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CONSTRUCTION OF FOLIAR KEY AND PHYLOGENETIC TREE FOR 114 HERBAGE VEGETABLES: A GLOBAL STUDY

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ABSTRACT

The term vegetable is usually applied to edible plants which store up reserve food which is eaten cooked or raw as the salad. Even though, a balanced diet requires ten ounces of vegetables per adult per a day, the present availability is only 1.3 ounces per adult per a day. To increase the consumption of vegetables, we must know about the various types of vegetables along with their identification. So, the present paper deals with the study of herbage vegetables that are distributed over 114 species belonging to 84 genera and 41 families. This knowledge of herbage vegetables would be of great use to business (restaurant) people and also to the researchers in the fields of herbal medicine, botany, biosystematics, taxonomy, Ayurveda, homeopathy, pharmaceuticals, and nutraceuticals.

KEYWORDS: Taxonomy, Dichotomous, Indented Key, Therapeutic, Geographic Distribution & Inflorescence

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Original Article

1. INTRODUCTION

The primary necessities of man are threefold – food, clothing and shelter. To fulfill his three folds, man uses the knowledge of botany. The food we eat primarily comes from plants in the form of cereals, millets, pulses, vegetables and fruits. Among these five, daily consumed food normally includes cereals, pulses and vegetables; Cereals for starch, pulses for protein and vegetables for minerals and vitamins. For clothing, he depends on the fiber yielding plants. For shelter, he depends on the timber yielding plants for the construction of the house. So, it becomes quite evident that knowledge of botany and its proper application lead to the well-being of humanity in several ways.

The term vegetable is usually applied to the edible plant parts which store up reserve food in roots, stems, leaves, vegetative buds, floral buds and fruits, which are eaten cooked or raw as a salad. Rimando simply defined vegetables as “crops usually grown for culinary purposes”. The nutritive value of vegetables is tremendous because of the presence of indispensable mineral salts and vitamins (Rimando, 2004). For a balanced diet, more and more utilization of vegetables is necessary. So, clear-cut knowledge on more types of vegetables is necessary. According to Hill, the vegetables can be grouped into three broad classifications based on their botanical parts that are edible and their location with respect to the ground (Hill, 1972). These include (1) Earth / underground vegetables are those in which the edible plants are below the ground including modified roots and stems; (2) Herbage vegetables are those with aboveground/aerial parts including stems, leaves, buds, flowers and inflorescence and (3) Fruit

vegetables are those in which the botanical fruits are usually cooked and rarely eaten raw except in salads.

Based on ethnobotanical studies, more number of herbage vegetables can be known from nature either weedy or cultivated plants. Most of the herbage vegetables that are known to mankind include leafy vegetables, which should be collected before flowering. The best advantages of cultivating herbage vegetables is that they have short harvesting time of few weeks, easily cultivated even on a terrace, grown all through the year, most of them are grown near the waste water and no much care is necessary for their growth. So, with less care, hard work and time, we can get high yields. The best time to collect all the herbage vegetables is in the evening times as plant stores energy from sunlight, a process known as photosynthesis, during daytime and at the night utilizes the stored food material.

Herbage vegetables are rich in water and proteins, sufficient amount of mineral salts and vitamins and a smaller amount of digestible carbohydrates. Hence, the herbage vegetables make an essential part of human diet. Hardly 10-15 types of herbage vegetables are in common use in cities and around 30 types of herbages in villages that are consumed by the local people. Most of the herbage vegetable consumption knowledge comes from traditional culinary practices and also from forefathers that pass from generation to generations.

The present study deals with the geographical distribution, parts used for the culinary purpose, identification by foliar key and phylogenetic tree construction of 114 herbage vegetables around the world. Our paper is the best source to identify and on keen observation of the paper, one can start consuming all or most of the herbage vegetables for the well-being and healthy mankind.

2. MATERIALS AND METHODS

2. 1 Plant Collection from the Field

All the herbage vegetables that were edible globally were first listed (M. Venkaiah, 2010; Pandey, 2005; Rao, 1999) from various sources such as books, internet and from the data given by the local people. Altogether we listed 114 plants and their edible part (table 1), which are easy to grow and are readily available almost all through the year. Plant material collection was done from the fields as mentioned elsewhere (Rasajna, 2017a, 2017b). All the plants were grown in loam soiled pots at the suitable environment with a continuous supply of air, water and sunlight.

Table 1: Table showing the Number of Herbage Plants that belong to their Corresponding Family and Herbage Edible Part Used

Part / type of Herbage Part used	Class/Sub Class	Families	Name of the Plant	No. of Genus	No. of Species	Total No. of Herbage Plants / Part Used
Normal stem	Monochlamydae	Chenopodiaceae	*Salicornia brachiata* Roxb.	01	01	02
	Polypetalae	Vitaceae	*Cissus quadrangularis* L.	01	01	
Modified stem	Polypetalae	Brassicaceae	*Brassica oleracea* L. var. *gongylodes* L.	01	01	02
		Cactaceae	*Opuntia ficus-indica* Mill.	01	01	
Vegetative buds	Polypetalae	Asteraceae	*Lactuca sativa* L.	01	01	04
	Gamopetalae	Brassicaceae	*Brassica oleracea* L. var. *capitata* *Brassica oleracea* var. *capitata* f. *rubra* L.	01	02	
	Monocots	Liliaceae	*Asparagus officinalis* L.	01	01	
Inflorescence	Monocots	Musaceae	*Musa sapientum L.*	01	01	01

axis/pseudo stem						
Immature inflorescence	Polypetalae	Brassicaceae	*Brassica oleracea* L. var. *botrytis* *Brassica oleracea* var. *italica* L.	01	02	04
	Gamopetalae	Asteraceae	*Cynara cardunculus* var. *scolymus* L.	01	01	
	Monocots	Musaceae	*Musa sapientum L.*	01	01	
Flowers/Flowers of Mature inflorescence/ Flower buds	Polypetalae	Brassicaceae	*Alliaria petiolata* (M.Bieb.) Cavara & Grande	01	01	12
		Caesalpinaceae	*Bauhinia variegata* L.	01	01	
		Capparidaceae	*Capparis spinosa* L.	01	01	
		Fabaceae	*Sesbania grandiflora* (L.) Poiret. *Trifolium pratense* L.	02	02	
		Malvaceae	*Hibiscus sabdariffa* L. *Malva sylvestris* L.	02	02	
		Meliaceae	*Azadirachta indica* A.Juss	01	01	
		Nympheaceae	*Nymphaea odorata* Aiton	01	01	
	Gamopetalae	Asteraceae	*Cichorium endivia* L.	01	01	
	Monochlamydae	Amaranthaceae	*Celosia argentea* L.	01	01	
	Monocots	Asphodelaceae	*Hemerocallis lilioasphodelus* L.	01	01	
Leaves	Polypetalae	Aizoaceae	*Gisekia pharnaceoides* L. *Glinus oppositifolius* (L.) Aug. DC. *Sesuvium portulacastrum* (L.) L. *Tetragonia tetragonioides* (Pallos) Kuntz *Trianthema decandra* L. *Trianthema portulacastrum* L.	05	06	
		Apiaceae	*Anethum graveolens* L. *Apium graveolens* L. *Centella asiatica* (L.) Urban *Coriandrum sativum* L.	04	04	
		Brassicaceae	*Alliaria petiolata* (M.Bieb.) Cavara & Grande *Brassica hirta* Moench. / *Sinapis alba* L. *Brassica juncea* (L.) Czern. *Brassica oleracea* L. var. *acephala* DC. *Brassica oleracea* L. var. *gemmifera* Zenk. *Brassica rapa* subsp. *Pekinensis* *Brassica rapa* var. *perviridis* *Brassica rapa* var. *rapa* L. *Eruca sativa* Mill.	05	11	

			Nasturtium officinale W.T.Aiton *Raphanus sativus* (L.) Domin			
		Caesalpinaceae	*Bauhinia variegata* L. *Cassia angustifolia* M.Vahl *Cassia fistula* L. *Cassia tora* / *Senna tora* (L.) Roxb. *Tamarindus indica* L.	03	05	
		Caprifoliaceae	*Valerianella locusta* (L.) Betcke	01	01	
		Capparidaceae	*Cleome gynandra* L.	01	01	
		Fabaceae	*Sesbania grandiflora* (L.) Poiret. *Trifolium repens* L. *Trigonella corniculata* (L.) L. *Trigonella foenum-graecum* L.	03	04	
		Geraniaceae	*Geranium robertianum* L.	01	01	
		Malvaceae	*Hibiscus cannabinus* L. *Hibiscus furcatus* Willd. *Hibiscus sabdariffa* L. *Malva sylvestris* L.	02	04	
		Mimosaceae	*Acacia concinna* (Willd.) DC.	01	01	
		Montiaceae	*Claytonia perfoliata* Donn ex Willd.	01	01	
		Moringaceae	*Moringa oleifera* Lam.	01	01	
		Nympheaceae	*Nymphaea odorata* Aiton	01	01	
		Oxalidaceae	*Oxalis corniculata* L.	01	01	
		Portulacaceae	*Portulaca oleracea* L. *Portulaca quadrifida* L. *Talinum triangulare* (Jacq.) Willd.	02	03	98
		Rutaceae	*Murraya koenigii* (L.) Spreng	01	01	
		Sapindaceae	*Cardiospermum halicacabum* L.	01	01	
		Saururaceae	*Houttuynia cordata* Thunb.	01	01	
		Tiliaceae	*Corchorus capsularis* L.	01	01	
		Vitaceae	*Cissus quadrangularis* L.	01	01	
	Gamopetalae	Asteraceae	*Achillea millefolium* L. *Cichorium intybus* L. *Eclipta alba* (L.) L. *Taraxacum officinale* (L.) Weber ex. F.H.Wigg	04	04	
		Convolvulaceae	*Ipomea reptans* Poir. / *Ipomea aquatica* Forsskal	01	01	
		Lamiaceae	*Coleus amboinicus* / *Plectranthus amboinicus* (Lour.) Spreng. *Glechoma hederacea* L.	05	05	

			Leucas aspera (Willd.) L. *Mentha arvensis* L. *Ocimum tenuiflorum* L./ *Ocimum sanctum* L.			
		Rubiaceae	*Canthium dicoccum* (Gaertn.) Merr.	01	01	
		Solanaceae	*Solanum nigrum* L. *Solanum trilobatum* L.	01	02	
	Monochlamydae	Amaranthaceae	*Achyranthes aspera* L. *Aerva lanata* (L.) Juss. ex Schult. *Allmania nodiflora* (L.) R.Br. ex Wight *Alternanthera pungens* Kunth *Alternanthera sessilis* (L.) R.Br. ex DC. *Amaranthus blitum* L. *Amaranthus cruentus* L. *Amaranthus dubius* Mart. ex Thell. *Amaranthus palmeri* S. Wats. *Amaranthus spinosus* L. *Amaranthus tricolor* L. / *Amaranthus gangeticus* L. *Amaranthus viridis* L. *Celosia argentea* L. *Digera muricata* (L.) Mart.	07	14	
		Basellaceae	*Basella alba* L. *Basella rubra* L.	01	02	
		Chenopodiaceae	*Atriplex hortensis* L. *Chenopodium album* L. *Spinacia oleracea* L. *Suaeda maritima* (L.) Dumort. *Suaeda monoica* Forssk. Ex J.F.Gmelin	04	05	
		Euphorbiaceae	*Acalypha indica* L. *Sauropus androgynus* (L.) Merr.	02	02	
		Nyctaginaceae	*Boerhavia diffusa* L. nom. Cons. *Mirabilis expansa* (Ruiz & Pav.) Standl.	02	02	
		Piperaceae	*Piper betle* L.	01	01	
		Polygonaceae	*Antigonon leptopus* Hook. & Arn. *Rheum rhabarbarum* L. *Rumex vesicarius* L.	03	03	
	Monocots	Araceae	*Colocasia antiquorum* Schott	01	01	
		Commelinaceae	*Commelina benghalensis* L.	01	01	
		Liliaceae	*Allium cepa* L.	01	01	
		Poaceae	*Bambusa vulgaris* Schrad.	02	02	

			ex J.C. Wendl. *Cynodon dactylon* (L.) Pers.			
	Pteridophyta	Marsileaceae	*Marsilea quadrifolia* L.	01	01	

2. 2 Construction of Taxonomic Dichotomous Foliar keys

A taxonomic dichotomous key was constructed as mentioned elsewhere (Rasajna, 2017a). Dichotomous (di-two, chotomy-forked) key is most common that consist of a series of paired statements, termed couplets, which describe some feature of the plant. The two characters of the couplets are known as leads, which are mutually exclusive (Sambamurthy AVSS, 2005). Indented or yoked keys indents the leads of the couplet an equal distance from the left margin (Griffing, 2011). We began with the first couplet and selected the statement that best fits our specimen, which then directed us to another couplet and ultimately helped us in generating the key and as this key was generated mainly basing on the leaf characters, it is termed as a foliar key and thus the final identification of our herbage plants was done using the generated foliar key.

2. 3 Construction of Phylogenetic Tree

Phylogenetic tree was generated by computers using bioinformatics. We first entered all the scientific names of the plants in National center for biotechnology information (NCBI) taxonomy homepage and constructed a taxonomy common tree. After construction, the data was saved in phylip tree format with.phy file extension. This saved file was uploaded in Phylodendron – phylogenetic tree printer, an online or offline software program PHY.FI (Fredslund, 2006). Once we upload and choose phenogram as our interested tree style to be constructed, the resultant phenogram can be downloaded in our desired format.

3. RESULTS

3. 1 General Identification and Grouping of Herbage Vegetables

All the 114 plants were observed and were identified as those herbage plants that were distributed among five classes as Polypetalae, Gamopetalae, Pteridophyta, Monochlamydae and monocots (Figure 1, A). Among the selected 114 for this study, maximum (45 %) herbage plants belong to the class Polypetalae whereas the minimum (1 %) belongs to Pteridophyta (Figure 1, A). Similarly, herbage plants with the edible part used other than leaves were also shown (Figure 1, B). Next to the leaves, the most common edible part used among the herbage vegetables include flowers/inflorescence (45 %), followed by buds (31 %) and the least include stem (24 %), including modified stem (Figure 1, B).

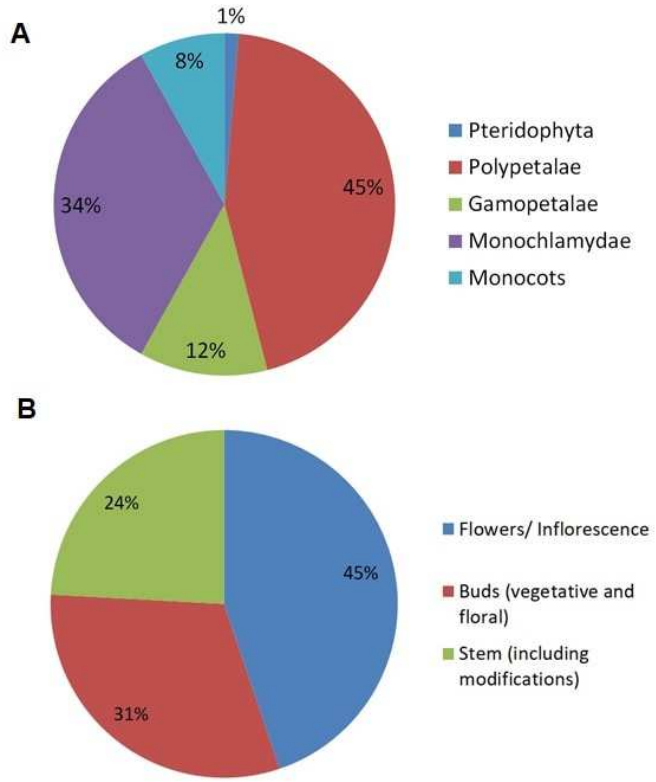

Figure 1: Distribution of Herbage Vegetables

The distribution of 114 herbage vegetables into various classes (A) and the edible part other than leaves (B).

3. 2 Taxonomic Identification of Herbage Plants by Constructing Dichotomous Foliar Key

For the proper identification of plants, we constructed and used an indented type of dichotomous key (Figure 2) that is commonly based on gross morphological features and characteristics that are readily observable in the field. The first lead of the first couplet, leaves are centric, helped us to identify the rounded type of leaf symmetry containing herbage plant *Allium cepa;* leaving all the bilateral leaf symmetry containing herbage plants with the second lead of the first couplet, leaves are not centric (Figure 2). Among the bilateral leaf symmetry containing herbages, we have identified all the 113 basing on 112 couplets and 224 leads. So, in total, the identification of 114 herbage vegetables using dichotomous foliar key was possible using 113 couplets and 226 leads (Figure 2).

Figure 2: Generation of the Taxonomic Dichotomous Indented Foliar key

A dichotomous indented foliar key was constructed for the characteristic identification of all the listed 114 herbage vegetables.

3. 3 Construction of Cladogram

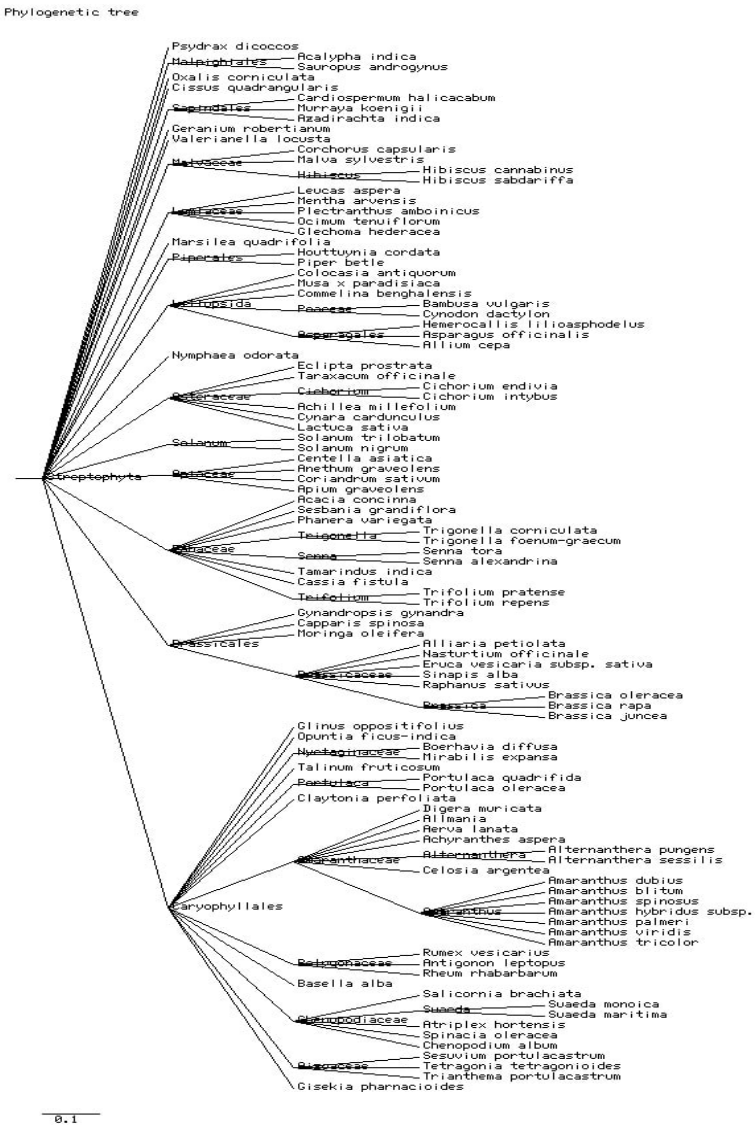

Figure 3: Construction of Cladogram

A rooted type of cladogram was constructed that helps in finding the phylogenetic and ancestral relationships among all the listed 114 herbage vegetables.

The cladogram shows us the phylogenetic and ancestral relationships among all the 114 herbage plants that were selected for our present study (Figure 3). We represented the phylogeny of all the herbage vegetables in the form of a cladogram, a rooted tree in which all the herbage vegetables share a common ancestor known as the root (Figure 3). In this type of tree, there exists a particular root node which represents a speciation event in evolution and beyond this point, any sequence change that occurred is specific for each branch (species) (Figure 3). The branch connects nodes of the tree and the length of each branch from one node to the next node represents the number of changes that occurred until the next separation (speciation). In the present tree, some nodes show the order and some show family depending on the ancestral

events and speciation that could have occurred (Figure 3). From this, it is very clear that most of the herbage plants belong to the order of Caryophyllales (Figure 3).

4. DISCUSSIONS

The countries that consume maximum herbages include China and India (Garland, 1993). Now-a-days, people from almost all countries consume herbages. But still, there are people who consider eating herbage vegetables is levity while the people who know the real value of consuming herbages are also increasing rapidly. Even the restaurants that intend to serve fresh greens hardly know around 20-40 varieties of herbages that are being cooked and served in various forms globally. But, the remaining herbage vegetables are either unaware or uncommon to most of the people. So, there is an immediate need to have a detailed knowledge of globally available herbage vegetables that not only increase the health of mankind but also leads to an increased income for restaurants that serve these typical foods prepared from numerous herbage varieties.

All the energy we get is from the food we eat. If we eat good food, we can be healthy as diet plays a key role in the prevention and control of various diseases (Burr, 1863). Almost all the herbage vegetables that were listed in Table 1 have therapeutic values and majority of them have antioxidant (Afsheen et al., 2018; Bajpai et al., 2005), anti-inflammatory (Fawole et al., 2010), anticancer (Asadi-Samani et al., 2018) antibacterial and antimicrobial properties in common. So ingestion of herbage vegetables itself protects us from various infections and boosts our immune system (Simonetti, 1990). Some herbage vegetables also show experimentally proved antidiabetic (Lans, 2006), antimalarial, anticholinesterase (Boga et al., 2011), antithrombin (Chistokhodova et al., 2002), hepatoprotective, gynecological problems (Balamurugan et al., 2018), cerebroprotective, etc., roles that prevents us from severe illness and maintains good health.

The tribes from Rampachodavaram forest, East Godavari District; Araku valley, Visakhapatnam district; Parvathipuram, Vizianagaram district; Srisailam, Kurnool district and Tirupati, Chittoor districts of Andhra Pradesh, India eat *Alternanthera sessilis* leaves for better vision; *Aerva lanata* leaves for urolithiasis; *Boerhavia diffusa* leaves for kidney and urinary problems; *Sesbania grandiflora* flowers for curing Madras eye, etc. At the same time, there are several other published and scientifically proved uses of not only these plants but of all the 114 herbage vegetables. For the correct identification of a plant that belongs to the class of herbage vegetables, a detailed and sound knowledge is necessary.

Keeping these in mind, our work shows the scientific and common names of the plants, their edible parts along with their proper identification for the normal people. For scientific identification of the plants, we have constructed an indented type of dichotomous foliar key, leaf morphology-based taxonomic identification key (Figure 2), for the characteristic identification of all the 114 herbage vegetable plants.

Next, to identification, the proper phylogeny and ancestral relationships of those plants are equally important for the researchers and this was attained by constructing the cladogram, a rooted tree (Figure 3). Our cladogram results showed similarity with that of Angiosperm Phylogeny Group (APG) system, a recent system, of classification. The cladogram results showed similarity with our constructed indented foliar key.

Our results also show that the plants belonging to Polypetalae were most commonly used as herbage vegetables and the parts that are edible, other than leaves, include flowers or inflorescence (Figure 1). The number of plants that belong to each herbage part and family was tabulated (Table 1). The present manuscript will be of great use to the people of various scientific fields and a lot of research has to be done on these herbage plants in the fields of biosystematics and

numerical taxonomy.

5. CONCLUSIONS

Herbage vegetables are plants with edible aboveground or aerial parts that include stem, leaves, buds, flowers, and inflorescences along with their modifications. 114 such herbage vegetables were gathered, collected, identified taxonomically by constructing the indented type of dichotomous foliar key and cladogram was constructed to find the phylogeny and ancestral relationships of all the herbage plants. This foliar key and phylogenetic tree help us in the characteristic identification of globally edible herbage plant parts used as vegetables for the well-being if humans.

AUTHORS CONTRIBUTIONS

GBVA selected, collected the data and identified them by constructing indented keys. NR collected the plants, classified them, contributed in experimental design and drafted the manuscript. All authors commented, read and approved the final manuscript.

COMPETING INTERESTS

The authors have had no financial, personal or other relationships with other people or organizations within five years of the beginning of the submitted work that could inappropriately influence, or be perceived to influence, their work. The authors declared that no competing interests exist.

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